On the Spin of the Mesotron

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In two papers in this issue of *The Physical Review* Christy and Kusaka[1] have given minimum estimates for the probability of radiative collisions by mesotrons, and have shown that these involve, for a mesotron of spin one and mass of the order of two hundred electron masses, a frequency of burst production greater by more than an order of magnitude than that actually found. In the case of mesotrons of zero spin the agreement with observation is good; in the case of mesotrons of spin $\frac{1}{2}$ and unit magnetic moment the calculated values exceed the experimental by a factor of about 1.6, a factor which probably lies within the uncertainties of the calculation, in particular the rather large uncertainty introduced by the unknown mass m of the mesotron. Nevertheless the many experimental indications of the beta-instability of mesotrons, and in particular the result of Nelson's analysis[2] of the data of Neher and Stever, that about one-half of the energy of mesotron decay is shower producing, would seem fully to have confirmed Yukawa's suggestion that mesotrons can disintegrate into electrons and neutrinos; and this would in our opinion make a half-integral value of the mesotron spin improbable. These arguments would then establish that the mesotron was described by a scalar or pseudoscalar field. It may be remarked in this connection that the neutron proton forces derived[3] from a charged pseudoscalar field by "classical" or perturbation-theoretic approximation agree in sign and spin dependence, though not of course in their singular dependence upon distance, with the sign and magnitude of the singlet triplet difference and the quadripole moment of the deuteron system, whereas the corresponding theory for charged mesotrons of unit spin gives a quadripole moment of wrong sign. The results of CK can thus not be regarded as adding a further difficulty to this in itself highly unsatisfactory theory of nuclear forces.

The calculations of CK give minimum estimates of burst production for the following reasons:

(1) They have in each case been made with that value of the magnetic moment which gives the smallest radiative probabilities compatible with the spin considered.

(2) They do not include nuclear collisions, and any electromagnetic or nuclear secondaries such collisions might produce.

(3) They include only those processes whose probability can legitimately be computed by perturbation theory; in them any contribution from processes that do not satisfy this condition has been discarded.

The first two points are fully discussed in the papers of CK, and of Corben and Schwinger.[4] It is only the last we wish to review here, since on this depends the cogency of the conclusions reached.

The radiative collisions of a mesotron of mass m and energy ξmc^2, $\xi \gg 1$, with the Coulomb field of a nucleus of charge Z and radius $\hbar Z^{\frac{1}{3}}/mc$, may with good approximation, insofar as they are extranuclear, be treated as the Compton scattering by the mesotron of the virtual quanta in the contracted field of the nucleus. In this coordinate system, where the mesotron is at rest, the maximum field acting on the mesotron, when it is nearest to the nucleus, is of the order $eZ^{\frac{1}{3}}\xi(mc/\hbar)^2$. The ratio of the interaction energy of this field with the mesotron charge and current is $Z^{\frac{1}{3}}\alpha^{\frac{1}{2}}(\alpha = e^2/\hbar c)$; and the probability of processes involving the absorption of n virtual quanta is small of the order $(\alpha Z^{\frac{2}{3}})^{n-1}$ compared to that of the absorption of one virtual quantum. This circumstance makes it possible to treat the effect of the various virtual quanta additively, and in particular to eliminate the possibility that the presence of a small intensity of high frequency quanta can sensibly alter the reaction of the mesotron to radiation of lower frequency.

For the further consideration of what happens when a quantum of frequency ν is absorbed by a mesotron, it is convenient to introduce a coordinate system in which mesotron and quantum have equal and opposite momenta, in which all momenta are of the order $P = (mh\nu)^{\frac{1}{2}}$, and all scattering processes are essentially isotropic. For the validity of the perturbation-theoretic treatment of the Compton effect, it is now further necessary that the coupling energy between light quanta of momentum P and mesotrons of momentum P be small compared to the energy of light quantum or mesotron, a condition which is satisfied if and only if $P < mc/\alpha^{\frac{1}{2}}$. This condition is not only necessary for the formal derivation of the scattering formula, but is also the condition that processes involving the simultaneous emission of several light quanta or several mesotron pairs be unlikely compared to the calculated process of simple scattering. In fact the relative probability that q quanta and p pairs be emitted is of the order $S_{q,p}(\alpha P^2/m^2c^2)^{q+2p}$, where the $S_{q,p}$ are numbers of order unity but presumably less than one, of which only the first, $S_{1,0} = (5/72)^{\frac{1}{2}}$, has been computed. For virtual quantum frequencies higher than $mc^2/h\alpha$, one may then expect the emission of large numbers of quanta and mesotron pairs: of these the former but not the latter will be burst-producing. For frequencies under this limit, multiple processes are unlikely, and there is no reason to expect competition[5] from them to reduce the probability of single scattering, or to doubt the applicability of perturbation theory.

What CK have done is to leave out altogether all scattering processes of virtual quanta of frequency above $mc^2/h\alpha$, and to show that their results on burst production, especially for the smaller burst sizes, are not at all critically dependent on the exact frequency of this "cut-off." It is true that the calculations of CK necessarily involve the application of the quantum theory of the electromagnetic field to space time regions smaller than any for which this theory has heretofore been directly verified. But apart from this it would seem that no valid argument could be found against the cogency of their conclusions.

[1] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 405, 414 (1941) quoted as CK.
[2] E. Nelson, Phys. Rev. **58**, 771 (1940).
[3] W. Rarita and J. Schwinger, Phys. Rev. **59**, 436 (1941). This result is obtained by using a pure pseudovector coupling, and introducing suitable square well potentials for the radial dependence of the forces.
[4] H. C. Corben and J. Schwinger, Phys. Rev. **58**, 953 (1940).
[5] See for instance L. Landau, J. Phys. USSR **2**, 483 (1940). I am indebted to Professor Pauli for calling to my attention the relevance of Landau's argument to the calculations of CK.